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ROADMAPPING – A SYSTEMATIC APPROACH TO OVERCOMING NGNP CHALLENGES

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ABSTRACT

Changing requirements, programmatic challenges, and technical risk hinder even the best projects. The Next Generation Nuclear Plant (NGNP) is a complex project with technical and programmatic uncertainty. This paper presents the path forward, methods, and tools used to understand the requirements, manage the uncertainty, and mitigate the risk for the NGNP project. The key tool, technology development roadmaps, is described in detail as a means to facilitate NGNP risk-informed decision making, technology down selection, and technology qualification and maturation.

Technology roadmaps for each NGNP System, Structure, or Component (SSC) were developed to set the vision for and drive the needed actions to down select technologies and designs; to assure technology readiness is demonstrated through testing, modeling, piloting, and prototyping; and to develop the test plans required to provide demonstrable evidence of the technology maturation required for codification and qualification. In the NGNP application, technology roadmaps provide the framework and structure required to systematically perform decision analysis, reduce risk, and mature technologies in a cost effective and timely manner. The steps followed include Structure Identification, Technology Readiness Assessment, Technology Selection, Technology Maturation, and Test Plan Development.

Technology roadmaps are generated for each of the critical NGNP SSCs, a sampling of which include:

(1) Reactor Pressure Vessel (including material selection, maturation, and qualification)
(2) Intermediate Heat Exchanger (including material, design, and secondary fluid selection and technology maturation)
(3) Circulator
(4) Hydrogen Production System (including technology selection and maturation)
(5) Class I Boundary Valves
(6) Fuel Material
(7) Core Graphite
(8) Steam generator
(9) Instrumentation and Controls
(10) Chemistry control systems for helium coolant with associated contaminants and impurities

This roadmapping process has helped to identify the key selection discriminators, tasks for down selection, current technology readiness level baseline, tasks to mature technologies, and test plans for selected Technology Readiness Level step change milestones. The roadmaps set the project course for technology selection, qualification, and maturation in a fashion that enhances project on-schedule and on-budget success.

1. INTRODUCTION

Changing requirements, programmatic challenges, and technical risk hinder even the best projects. The Next Generation Nuclear Plant (NGNP) is a complex project with technical and programmatic uncertainty. This paper presents the path forward, methods, and tools used to understand the requirements, manage the uncertainty, and mitigate the risk for the NGNP project. Technology development roadmaps are a

key tool used to assist in performing this key function and are described in detail as a means to facilitate NGNP risk-informed decision making, technology down selection, and technology qualification and maturation.

Technology roadmaps for each NGNP System, Structure, or Component (SSC) are developed to

(1) Set the vision for and drive the needed actions to down select technologies and designs;

(2) Assure technology readiness is demonstrated through testing, modeling, piloting, and prototyping; and

(3) Identify the test plans required to provide demonstrable evidence of the technology maturation.

The five steps of technology roadmap development are depicted in Figure 1.

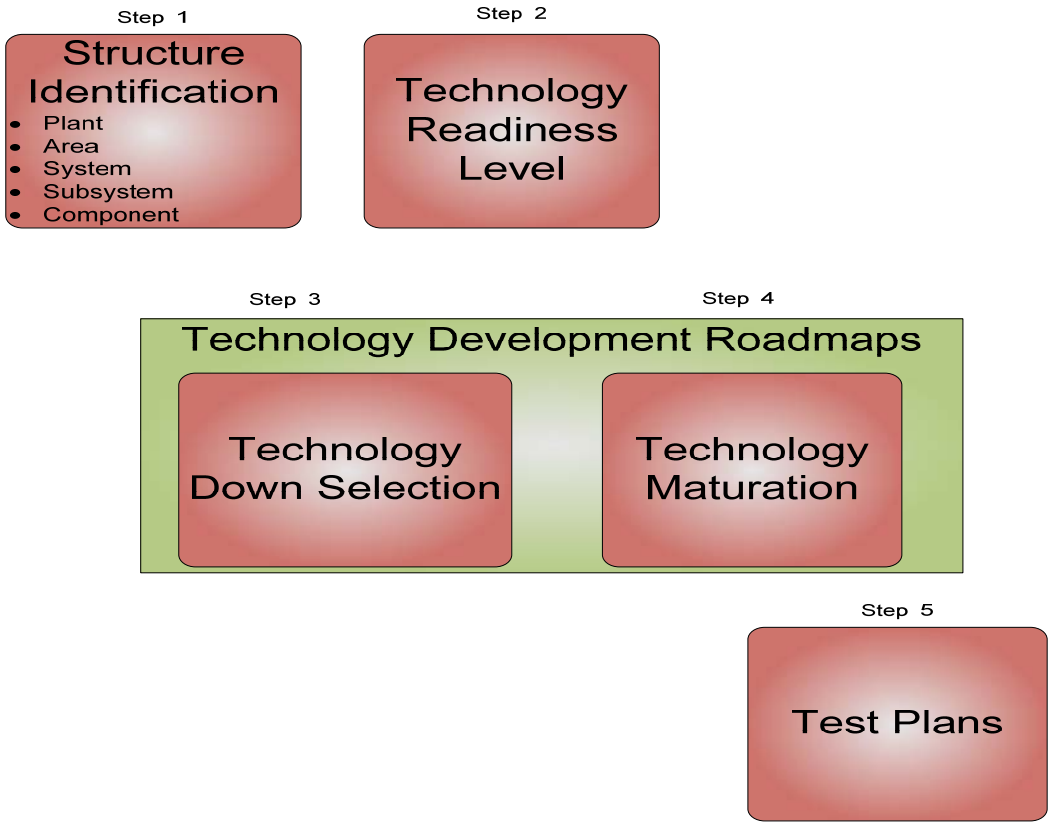

Fig. 1 Roadmapping - A Five Step Process

2. IDENTIFY COMPONENTS REQUIRED TO MEET NGNP FUNCTIONS

Identification of the physical structure needed to satisfy the desired functions of the NGNP is performed in step one. Although numerous options exist to satisfy the desired functions, each option contain Systems, Structures, and Components (SSCs) that comprise each of five areas which in turn comprise the NGNP. These five items comprise the NGNP Plant, Area, Systems, Structures, and Components (PASSC). The five plant areas required to satisfy the required functions are the

(1) Nuclear Heat Supply,
(2) Heat Transfer,
(3) Power Conversion,
(4) Hydrogen Production, and
(5) Balance of Plant.

Each of these five areas is further divided into systems, which are divided into structures, which are further divided into components. An example set of the PASSCs for the NGNP are shown in Figure 2.

CI	Island	System	Structure	Component	TRL
Top					4
1	**Nuclear Heat Supply**				3
1.1		Reactor Unit System			1
1.1.1			Fuel Elements (spheres)		1
1.1.2			Core Internal Structure (metallic, graphite, ceramic)		1
1.1.3			Reactivity Control System		1
1.1.4			Reactor Pressure Vessel		1
1.2		Core Conditioning System			4
1.3		Reactor Cavity Cooling System			4
1.4		Fuel Handling and Storage System			4
1.5		Helium Service System			3
2	**Heat Transport**				4
2.1		Primary Heat Transport System (PHTS)			3
2.1.1			PHTS Circulator		2
2.1.2			PHTS Valve		2
2.1.3			Intermediate Heat Exchanger (IHX)		3
2.1.3.1				IHX Core	1
2.1.3.2				Internal Ducts, Supports and Insulation	4
2.1.3.3				IHX Vessel, Supports and Insulation	5
2.1.4			Piping (Reactor tIHX - both hot and cold legs)		5
2.1.4.1				Pressure Boundary Piping, Including External Supports and Insulation	4
2.1.4.2				Piping Internal Ducts, Supports and Insulation	5
2.2		Secondary Heat Transport System (SHTS)			4
2.2.1			SHTS Circulator		4
2.2.2			Helium Isolation Valves (if required)		4
2.2.3			Piping (both hot and cold legs, plus PCHX tSG)		5
2.2.3.1				Pressure Boundary Piping, Including External Supports and	4
2.2.3.2				Piping Internal Ducts, Supports and Insulation	5
2.2.4			SHTS Flow Coupling and Mixer		4
3	**Hydrogen Production**				3
3.1		Sulfuric Acid Decomposition System			1
3.1.1			Sulfuric Acid Decomposition Reactor (PCHX)		1
3.2		Electrolysis System			5
3.2.1			Electrolyzer		5
4	**Power Conversion**				6
4.1		Main Steam System			6
4.1.1			Steam Generator		6
5	**Balance of Plant**				4
5.1		I&C			4

Fig. 2 Technology Readiness for the Plant, Area, Systems, Structures, and Components

3. ASSESS TECHNOLOGY READINESS

With the identification of the required PASSCs, we evaluate each SSC for readiness to be deployed in the NGNP. Technology Readiness Levels (TRLs) 1 through 10 are defined as shown in Figure 3, and in Step 2 each of the components is rated and assigned a TRL. The TRLs are validated during which evidence is reviewed to justify the maturity of each technology and associated SSC. Once the TRLs are validated for each SSC, a TRL baseline is established for the physical design being proposed. This design becomes one scenario for satisfying the NGNP functional requirements. As other designs are developed and proposed, they too are assessed for TRL and rolled up to an overall NGNP TRL, which is then compared to other scenarios. Figure 2 depicts TRLs for each component with roll up to the complete NGNP for one scenario.

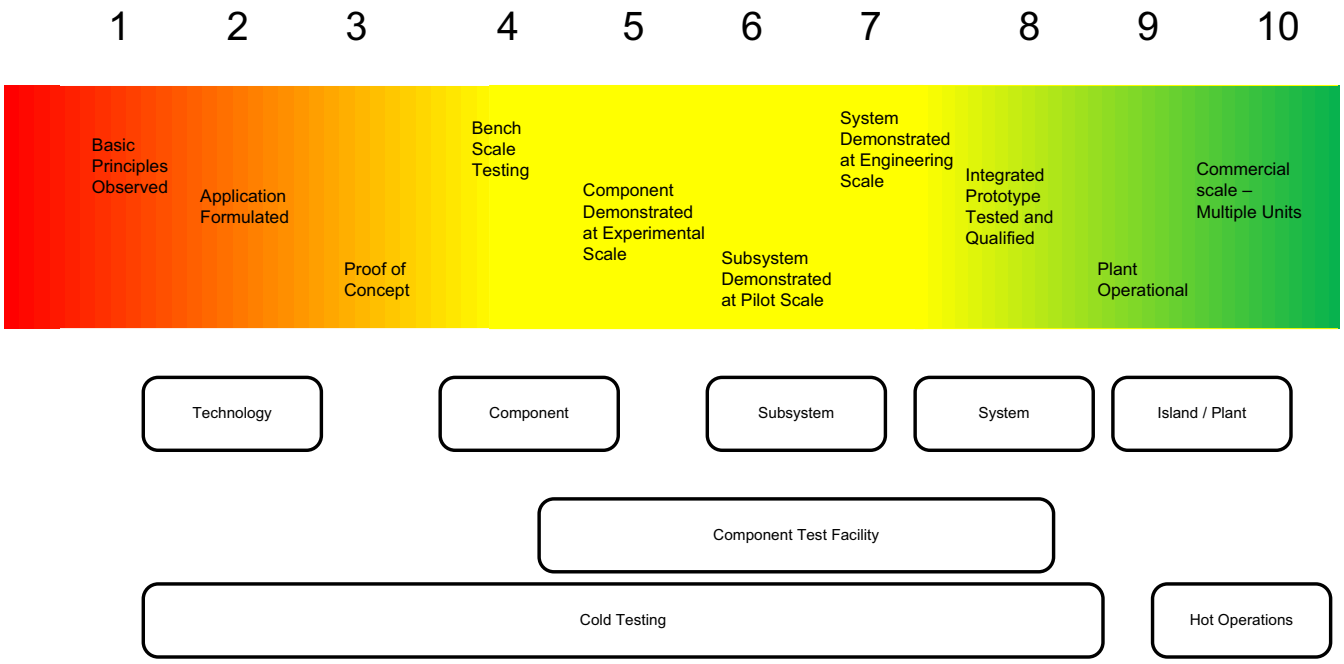

Fig. 3 Structured Progression through Technology Readiness Levels Reduces Project Risk

General rules of thumb for the higher level TRLs have been adapted from the National Aeronautic and Space Administration (NASA) and the Department of Defense (DOD) and are applied to the NGNP as follows:

(1) A validated TRL of 5 is required prior to component down selection at a sufficiently reduced level of uncertainty.

(2) A validated TRL of 6 is required for preliminary design as a means of reducing project risk.

(3) A validated TRL of 7 (Engineering Scale) is required for final design. For many systems this will require a large-scale testing facility (i.e., Component Test Facility, Reference 1).

(4) A validated TRL of 8 is prototype scale with full integration. Many systems will not achieve this level until full system operability testing in the NGNP is complete. The full NGNP is granted a TRL of 8 when system operability testing is complete and a Declaration of Readiness is issued by the project.

(5) A validated TRL of 9 is achieved for most NGNP systems only when the NGNP is fully operational (i.e., producing full power to the grid).

(6) A validated TRL of 10 is achieved as the NGNP is replicated commercially.

4. SELECT TECHNOLOGIES

With the baseline PASSCs and their associated TRLs in place, Step 3, Technology Down Selection, is performed and decision discriminators are developed. Here a list is developed of the important parameters that a successful technology would have to satisfy to assist NGNP in meeting its mission. This list of parameters is then consolidated into three to seven key selection discriminators that focus the data collection on the parameters important to the NGNP, namely those that distinguish one technology from another. Typically, technology or components must be matured to a TRL of 5 to reduce the certainty and understand the technology and to reduce the risk sufficiently to proceed with down selection. Where appropriate, the units of the discriminator are determined. This assures that the discriminator is indeed measureable. Step 3 Technology Down Selection tasks are as follows:

(1) Identify all decision discriminators

(2) Consolidate decision discriminators

(3) Define decision discriminators (units and equations)

(4) Determine level of data needed (qualitative, semi-quantitative, quantitative)

(5) Determine the tasks required to obtain the discriminating information necessary to perform the comparison of alternatives and ultimate down selection. These tasks will include studies, tests, evaluations, modeling, qualitative analysis, and quantitative analysis.

For the hydrogen roadmap, selection between three competing technologies was needed. Here seven discriminating parameters were selected and the tasks were identified to provide the data for the parameters. As shown in Figure 4, a TRL of 5 is desired before a down selection decision can be made with an acceptable level of certainty.

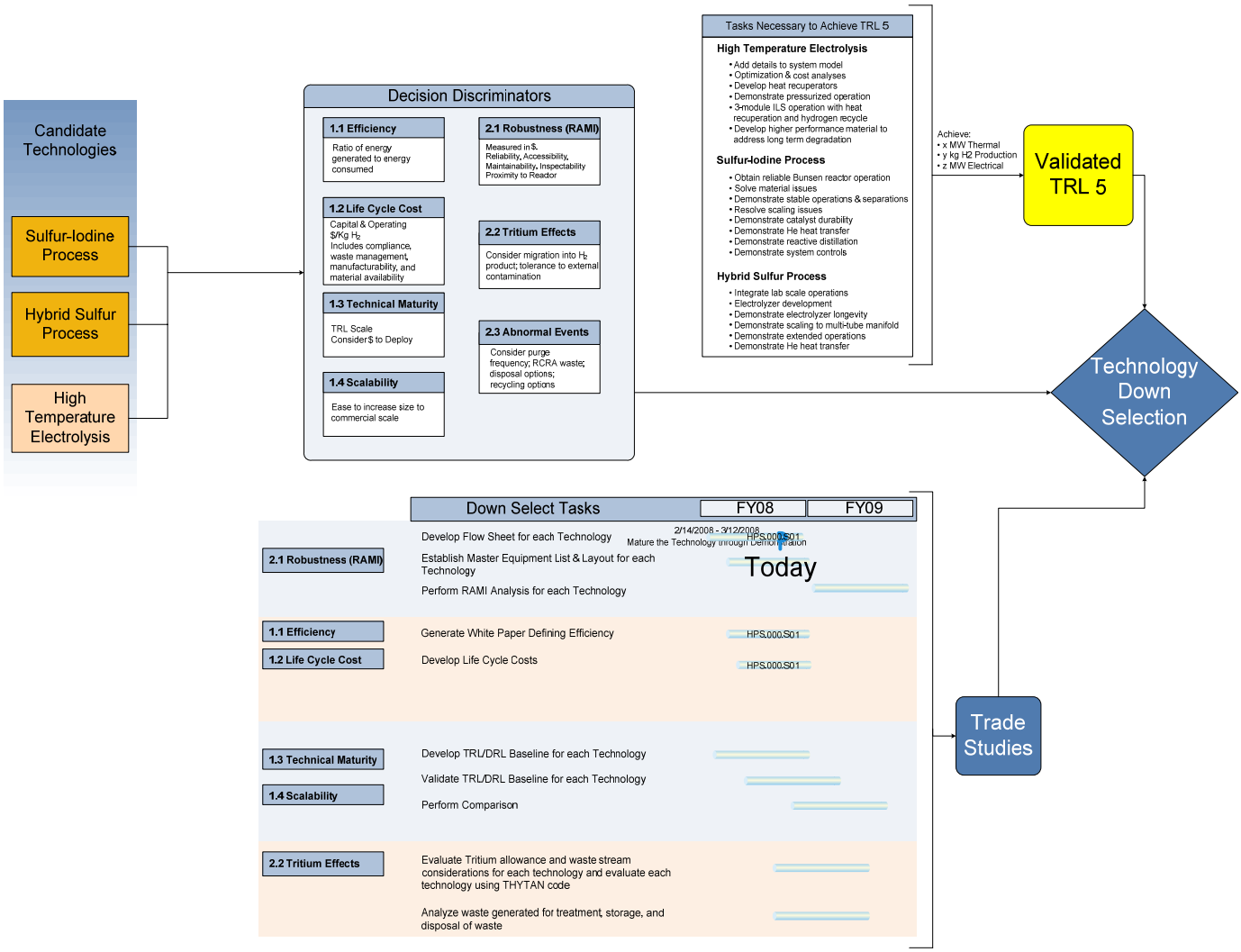

FIG. 4 DECISION DISCRIMINATORS FACILITATE TECHNOLOGY DOWN SELECT

5. MATURE THE TECHNOLOGIES

The technology development roadmap focuses the research and development efforts and engineering studies on the known risks to advancing the technology and satisfying the increasingly demanding and scaled up tests Tasks will include modeling, tests, bench scale demonstrations, pilot scale demonstrations, and full integrated prototype demonstrations. Step 4 refines the TRL definitions specific to the component or system being evaluated and determines the tasks required to advance the readiness levels of each SSC.. Here a vision for the maturity of the technology is established to achieve the required TRL. For example, a TRL of 5 is defined as a component having being tested at an experimental scale.

For hydrogen production, this could be defined as an Integrated Loop Skid that must produce 10 kg of hydrogen per minute over a 72 hour test. Herein, the NGNP sets the vision for the component and helps the technology development program to focus all efforts toward these specific and measureable demonstrable milestones.

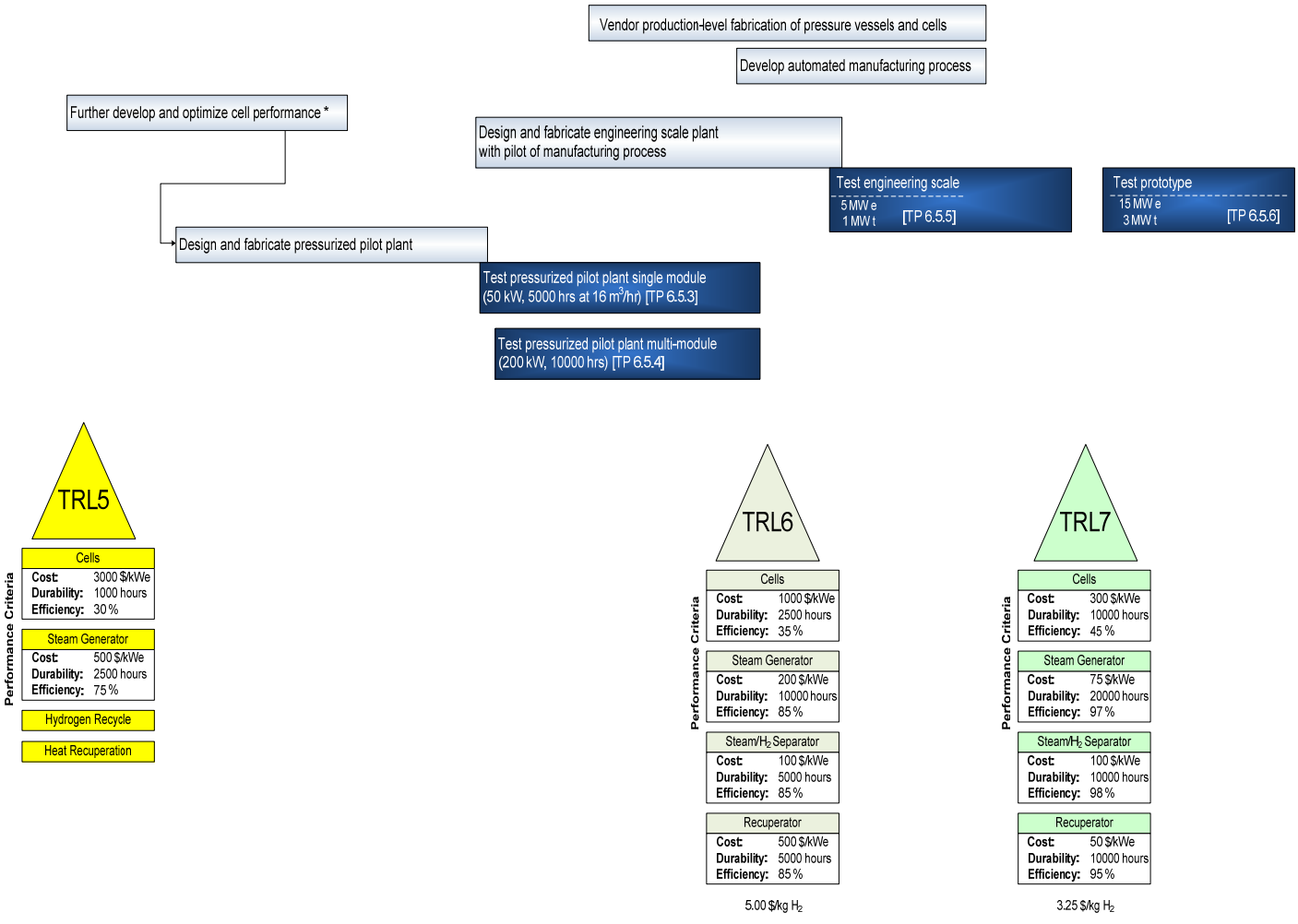

Fig. 5 Technology Maturation Tests Increase Readiness

6. ESTABLISH TEST PLANS

Test Plans are established for all the NGNP high-temperature and critical SSCs, including high-temperature heat applications. These test plans are specific to the SSC and identify the current SSC TRL and all research; modeling; and laboratory, bench-scale, environmental, pilot-scale, integrated, and engineering-scale testing required to advance the technology from its current level of readiness to the next level and subsequent levels through a TRL level of 8. Included in the test plans are the test objective, the duration of the test, the scale of the test, and the proposed location. Additionally, the items to be tested, the features to be tested, the test approach, the pass/fail criteria, safety considerations, and test deliverables are included in the test plan. These test plans are used to determine which testing functions required for full technology maturation exist, and which functions do not exist and need to be created in facilities such as the Component Test Facility.

This roadmapping process has helped to identify the key selection discriminators, tasks for down selection, current technology readiness level baseline, tasks to mature technologies, and test plans for selected Technology Readiness Level step change milestones. The roadmaps set the project course for technology selection, qualification, and maturation in a fashion that enhances project on-schedule and on-budget success.

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